Institute of Polar Studies

Report No. 5

The Scientific Observations of the Ross Sea Party of the Imperial Trans-Antarctic Expedition of 1914-1917

by

Fritz Loewe

Institute of Polar Studies

February 1963

CORRECTION SHEET

Institute of Polar Studies, Report No. 5
"The Scientific Observations of the Ross Sea Party of the Imperial Trans-Antarctic Expedition of 1914-1917" by F. Loewe

p. 2, line 11 from bottom, read: time of the preceding day

p. 4. Place the last sentence of the 2nd paragraph "Hence, ..." after "except 1911" on the 5th line of the same paragraph.

p. 5, 3rd paragraph, read: characterized by considerable

p. 6, line 6 from bottom, read:...explanation. The coefficient....

p. 7, line 6, read: ...used here; it gives....

p. 9, line 15 from bottom, read: ...deviations $\sigma\Delta c$ and $\sigma\Delta W$

p. 9, second table, heading of second column of numbers, read: $\sigma\Delta c$ (/8)

p. 11, line 11, read: Island, (Argentina, 1951).

p. 12, line 12 from bottom, read: (Table XVII).

p. 15, line 9 from bottom, read: ...Beaufort, and of the days with strong gale,

p. 15, line 8 from bottom, read: winds ≥ 22 m/sec,

p. 15, line 4 from bottom, read: Cape Evans

p. 16, line 20 from bottom, read: Possibly, the huge Erebus massif immediately to the east....

p. 16, line 9 from bottom, read: distribution of gales during 1916.

p. 17, line 13, read: speeds are given in ....

p. 19, line 2, read: measuring of humidity....

p. 20, line 20, read: In one case, the observer remarked....

p. 22, line 5 from bottom read: ...difference is

p. 23, line 15, read: ...during a given month without...into consideration. The frequency distributions....

p. 24, last line read: prevailingly diurnal type

Table XXIV, last column, read: ≥ 75, and ≥ 33

INSTITUTE OF POLAR STUDIES

Report No. 5

THE SCIENTIFIC OBSERVATIONS OF THE ROSS SEA PARTY OF THE IMPERIAL TRANS-ANTARCTIC EXPEDITION 1914-1917

by

Fritz Loewe

Institute of Polar Studies

The Ohio State University
Columbus 10, Ohio

January 1963

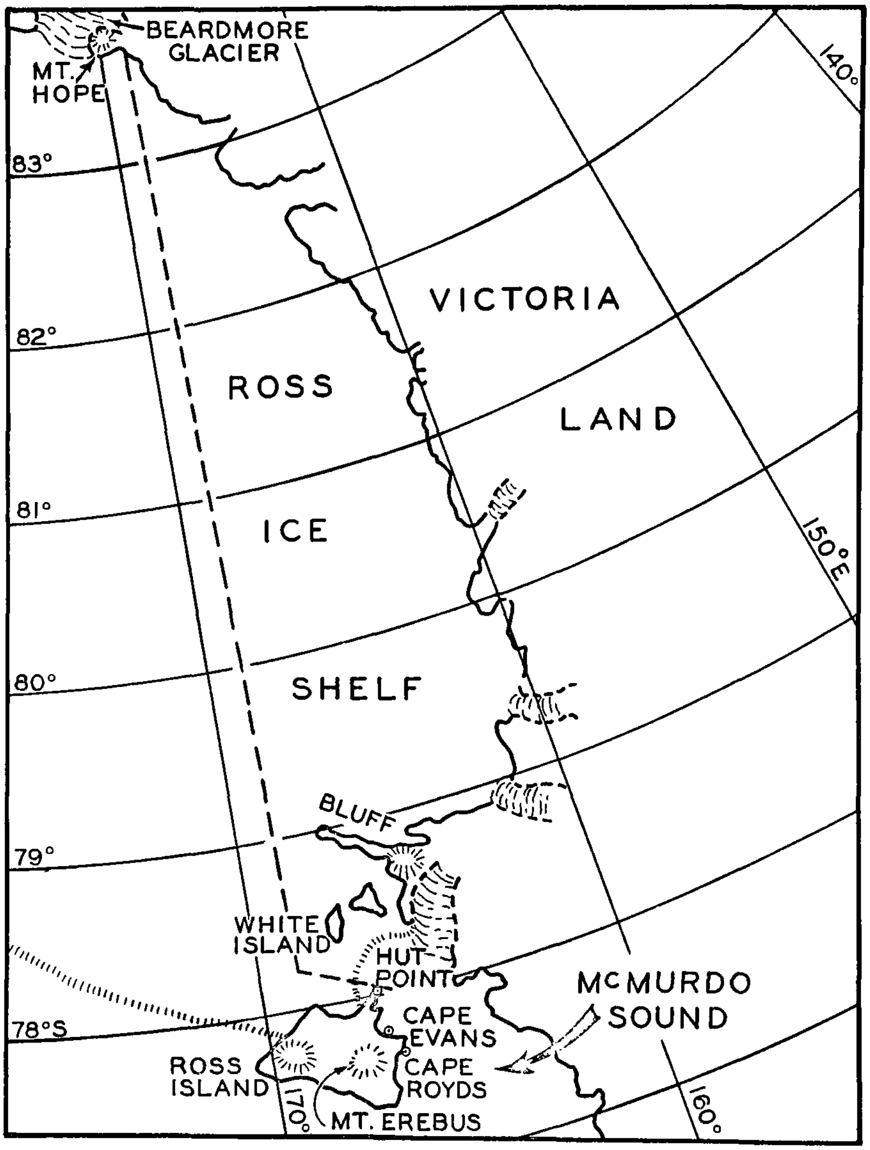
ABSTRACT

During 1915-1917 the Ross Sea Party of the Imperial Trans-Antarctic Expedition wintered in McMurdo Sound and sledged across the Ross Ice Shelf to the foot of the Beardmore Glacier.

The meteorological observations made during this time, mainly at Cape Evans (77°38'S, 166°24'E), are discussed. It was found that the meteorological conditions differed little from those found during other years in McMurdo Sound. The mean annual temperatures were slightly higher than the average temperature over 12 years in McMurdo Sound. The temperatures from May to September were almost uniform. Except for midsummer, the temperatures rose with cloudiness and wind speed. In autumn, temperatures on the Ross Ice Shelf dropped very rapidly compared with those at the coast. As in earlier years, Cape Evans proved to be a windy place. Throughout the year most of the winds and almost all of the gales came from the southeast. During the winter the mean water vapor pressure was very close to equilibrium with an ice surface. Evaporation from a lake surface in winter was about 0.1 mm/day. The tides were of the mixed, prevailingly diurnal type. The spring tide range was about 125 cm.

CONTENTS

TABLES: SEE APPENDIX


BEARDMORE GLACIER
MT. HOPE
83°
82°
81°
80°
79°
78°S
140°
150°E
160°
170°
VICTORIA
LAND
ROSS
ICE
SHELF
BLUFF
WHITE ISLAND
HUT POINT
McMURDO SOUND
CAPE EVANS
CAPE ROYDS
ROSS ISLAND
MT. EREBUS

THE SCIENTIFIC OBSERVATIONS OF THE ROSS SEA PARTY OF THE IMPERIAL TRANS-ANTARCTIC EXPEDITION 1914-1917

INTRODUCTION

Sir Ernest Shackleton had planned a two-sectioned expedition in the southern summer of 1914-1915. One section of the expedition was to land on the Filchner Ice Shelf in the southeastern Weddell Sea and establish a base there, sledge across the polar plateau to the Ross Ice Shelf, descending the Beardmore Glacier, and arrive at McMurdo Sound in the southwestern corner of the Ross Sea. The other section of the expedition was sent to the Ross Sea to set up the necessary food and fuel depots for the later part of the intended crossing of the continent.

Both parties suffered great hardships. The ship of the Weddell Sea section was beset before a landing could be effected and was later crushed in the ice. The "Aurora," the ship of the Ross Sea section, having been moored for the winter at Cape Evans, drifted away in May 1915 with most of the equipment and food of the shore party. The ship remained ice-bound throughout the winter, spring, and summer, and was not released until 14 March 1916 in the very low latitude of 62 1/2°S, 157 1/2°E (according to Wordie, 1921, at 64 1/2°S, 161°E). While drifting, the members still aboard the ship made meteorological observations which are still the only winter observation from this side of the Antarctic waters. Their observations, unfortunately, have disappeared (Wordie, 1921) and repeated searches for them have been fruitless. The history of the expedition was written by Shackleton (1919); the meteorological results of the Weddell Sea Party were summarized by R. C. Mossman (1921)

The ten members of the shore party in the Ross Sea section established themselves in the hut of Scott's second expedition, which is at Cape Evans (77°38'S, 166°24'E) at the foot of Mt. Erebus. Subsequently, some of them made trips to Hut Point (77°51'S, 166°45'E), the winter station of Scott's first expedition and were detained there by ice conditions for long periods. They made numerous sledging trips over the Ross Ice Shelf towards the south to establish the depots. During the longest of these trips, they went onto the ice shelf in November 1915, reached Mt. Hope at the foot of the Beardmore Glacier in latitude 83 1/2° on 26 January 1916, and returned to Hut Point on Ross Island in the middle of March. In spite of scanty equipment and frequently difficult living and sledging conditions, the Ross Sea Party made extensive and careful scientific observations, meteorological ones in particular. This work was shared mainly by the three scientific members: A. Stevens, R. W. Richards, and A. K. Jack, all of whom are still alive. During the absence of his companions, Stevens singlehandedly made four-hourly weather observations day and night for ten weeks. Preliminary evaluations of some of the data have already been made in the field. The original observations and calculations have been carefully preserved for 45 years by Mr. Jack. They are now at the Scott Polar Research Institute in Cambridge, England.

ACKNOWLEDGMENTS

I am grateful to the Scott Polar Institute for permission to work on these historical data, and to the Institute of Polar Studies, Ohio State University, which offered me hospitality and the facilities of the University while I reduced and analyzed the data. I thank the surviving members of the expedition and the many other persons who have supplied me with information.

THE OBSERVATIONS

The scientific work of the Ross Sea Party included observations on meteorology, glaciology, oceanography, and study of the aurora. The meteorological logbook at Cape Evans starts on 25 March 1915 and, with very few gaps, continues to 8 January 1917. Starting at 3 a.m. local time, which, for practical purposes, corresponds to 4 p.m. world time, generally six four-hourly observations were taken a day. They include: pressure as recorded by a mercury barometer and a barograph; temperatures taken from dry bulb, maximum, minimum, solar maximum and terrestrial minimum thermometers and a thermograph; humidity from a hair hygrometer and some wet bulb readings; wind direction and strength from a recording anemometer; cloudiness; frequency of precipitation and snow drift; and the direction of the smoke plume of Erebus. Very detailed observations of the sky cover and the weather conditions were also made. Some minor glaciological observations have already been published (Loewe 1961a, 1961b).

TEMPERATURES AT CAPE EVANS

Monthly and Daily Mean Temperatures

Table I contains the mean monthly temperatures at Cape Evans from 23 March 1915 to 8 January 1917. (Tables are at the end of the report.) The mean annual temperature 1915-16 of 14.9° is slightly higher than the annual temperatures measures at Cape Evans during the Terra Nova Expedition: -18.0° (in 1911) and -16.0° (in 1912), (Simpson, 1919). The difference, however, is within the range of the normal variation. The temperatures display the well-known feature of the "coreless" winter in a very marked way for any given year when any of the months from May to September might be the coldest. The fact that December is warmer than January might also be a characteristic feature of the climate of McMurdo Sound. The high February temperature of 1916 is exceptional, being the warmest of the eleven February months at McMurdo Sound that have been recorded to date. Table I also contains the mean temperatures of 11 to 13 years between 1902 and 1961 in McMurdo Sound, on Hut Point Peninsula, at Cape Evans and at Cape Royds.

The differences between the warmest and the coldest day of each month (Table I) were twice as large in winter as in summer. The greater temperature variability in winter will be referred to repeatedly in the following discussion. In summer, the coldest days deviated more from the general average than the warmest days; strong temperature rises were blocked at that time because, at the freezing point, most heat is used to melt snow and ice. Conversely, in winter, the warmest days, in general, deviated more from the monthly mean than the coldest days. This results from the occasional strong heating caused by the removal of the customery cold layer near the ground and by the influx of warm air.

Extreme Shelter Temperatures

Table II contains the means of the daily extreme temperatures measured by maximum and minimum thermometers in the meteorological shelter at Cape Evans.

The mean temperature calculated from the monthly mean maxima and minima does not differ systematically from the mean of the four-hourly observations. This result differs from those of Simpson (1919) and Kidson (1930), both of whom find that the mean of the daily extremes is systematically lower than the true average. This finding, incidentally, is contrary to the common experience in other climates (Brooks, 1917). The mean unperiodic daily temperature range was greater in winter than in summer. The greatest temperature variations during a 24-hour period, as shown in the last line of Table II, exceeded 20°. The values are very similar to those found by Scott's expeditions; the mean daily range was greater at Cape Royds (Kidson, 1930).

Table II also shows that the size of the mean daily temperature range was more closely connected with the mean daily minimum than with the mean maximum temperatures. The coefficients of correlation between the size ranks of the mean monthly ranges and the mean monthly minimum, and the mean monthly ranges and the mean monthly maximum are in the first case -.93° and -.76° in the second. This corroborates Simpson's statement that in regions with a prevailing inversion of temperature near the ground, the daily range is influenced more by the minimum than maximum temperatures.

The absolute temperature maxima of the summer months (1915-1917) tended to remain below the highest summer maxima of earlier years, but exceeded the freezing point by a small amount. The absolute maximum of +2.6° on 18 January 1916 is lower than the maxima of all other years except 1911. The extreme maxima during the winter months, April to October, were very high; they were, with the exception of September, higher than those observed at McMurdo Sound during the earlier five years of observations. Consequently, solid ice did not form in McMurdo Sound before June. The extreme minima were high, too. On the average they were 12° higher for the months from March to October than the minima observed during five years of earlier observations. The absolute minima of -38.6° on 15 July 1915 and of -37.2° on 31 August and 5 September 1916 are higher than those of any preceding year. Hence, the monthly absolute range in the summer was smaller than it was in earlier years.

Table III gives the number of days on which the temperature rose higher than freezing point. In 1915 and 1916, Cape Evans had 337 "ice days" per year; and in 1911 and 1912, 360. This very marked difference might raise some doubt concerning the later period, but nearby Cape Royds records similarly small numbers.

Terrestrial Minima

Terrestrial temperature minima were observed from April 1915 to mid-May 1916. Until October 1915 they were obtained by a terrestrial minimum thermometer. It is not known with what instrument they were read during the months from October to May. The observations were taken either twice daily (7 a.m. and 7 p.m.) or only once (7 a.m.). The monthly means of the differences between the minimum temperatures at shelter level and the concurrent minima at a short distance above the surface are given in Table IV, based on 334 days of observations.

During the periods when a substantial part of the day was dark, the terrestrial minimum temperatures were considerably lower than the minimum temperatures in the shelter. The differences are surprisingly great. The lowest terrestrial minimum, -45.3^{o}, corresponds to the lowest shelter minimum, -38.5^{o}. The big difference suggests a strong inversion of temperature in the lowest two yards. The terrestrial thermometer was probably frequently covered by drifting snow and thus would have acted like a kind of wet-bulb thermometer. It is likely, too, that the terrestrial thermometer was colder than the snow surface itself, for the surface, when strongly cooled by radiation, receives heat from the deeper snow layers by conduction. The terrestrial thermometer might further have experienced short periods of cooling near the ground that are not felt at shelter level. Nevertheless, the careful observations of Dalrymple (1961) at the South Pole do not show any comparable lowering of the temperatures near the ground. Thus the suspicion of instrumental errors at ground level remains.

During the midsummer months of continuous sunshine the terrestrial minima were, on the average, slightly higher than the shelter minima. This may be due partly to actual warmer temperatures near the ground as found by Dalrymple (1961) and partly to the absorption by the thermometer of radiation reflected from the snow-covered ground. These observations correspond well with summer observations made elsewhere, thus making it difficult to regard the aforementioned winter observations of the terrestrial minimum as erroneous.

Daily Temperature Variations

The polar regions are generally, and particularly in winter, characterized by a considerable aperiodic daily temperature fluctuations. Their monthly means have been given in Table II. The periodic temperature variations, however, are substantial only in summer and become very small in winter. Table V shows the mean deviations from the mean of the month of the six four-hourly observations. The data have been corrected for non-cyclical changes of temperature.

The periodic diurnal variation is derived from observations made between April 1915 and December 1916. Its range was decidedly greatest before the summer solstice. In these two years it represents Simpson's "Fram type," not his "McMurdo type" (Simpson, 1919). From about May to August, during the periods without sunshine, the diurnal variation has been extensively discussed by Simpson (1919) and Kidson (1930). The present four-hourly observations are, perhaps, not spaced quite closely enough for a detailed study of the very small deviations. The only marked feature seems to be a slight rise of temperature near midnight

(Table V) which has also been noted elsewhere in polar regions. But a closer inspection shows that the two years 1915 and 1916 differ considerably. The last two lines of Table V reveal the differences between the two years. The first one gives the amplitudes of the combined daily variation for 1915-1916 as derived from the combined four-hourly values of Table V. The second one gives the means of the amplitudes of the diurnal variation during each of the two years, irrespective of the time of occurrence of the extreme temperatures. The divergence of the two amplitudes during the winter months shows that the daily variations during the two years must have been quite dissimilar. This is apparent when the 24 deviations from the monthly means at the different observation hours for the months from May to August 1915 and 1916 are correlated; the resulting coefficient of correlation is -.45, negative and probably fortuitously large. Hence, no importance can be attached to the rise of temperature near midnight.

The daily temperature range of Table II represents the aperiodic weather variations as well as the variations caused by the periodic diurnal temperature range. In order to obtain the true aperiodic range that is caused by the variability of the weather, the periodic temperature variation has been subtracted from the range of Table II. The difference is the "reduced range" (Simpson, 1919) shown in Table VI.

The mean monthly reduced temperature range for 1915-1916 is markedly smaller than the values for all years at McMurdo Sound that are shown in the second line of Table VI. The small reduced temperature range at Cape Evans is not restricted to 1915-1916, but occurs in all four years of observations at that place. Kidson (1930) has already noted that the minimum temperatures in the cold layer are less marked at Cape Evans than they are at Cape Royds or Hut Point.

As is generally the case, the reduced temperature range, which represents the influence of the weather, is larger in winter than in summer. At McMurdo Sound temperature changes in the winter depend mainly upon the disturbances of the cold surface layer, and these in turn depend upon the strength of the wind. Simpson (1919) has pointed out that the wind force influences the minimum temperatures more than it does the maximum, and he has given an explanation. However, the coefficient of correlation between the ten monthly reduced daily ranges and the mean monthly minimum temperatures for May to September 1915 and 1916 is -0.6, which is slightly smaller than that found by Simpson (1919). The correlation with the maximum temperatures is not significant.

Interdiurnal Temperature Variations

The variability of the temperatures caused by the weather is indicated by the interdiurnal temperature variation. It can be represented either by the temperature changes from day to day at a given hour as done for Cape Evans by Simpson (1919), or by the changes of the daily mean temperature from one day to the next. The latter method is used here because it gives smaller values than the former. Table VII contains the monthly means of the daily temperature variation separated according to rises and falls, and the frequencies, n, of rises and falls of the mean daily temperature.

On the average, the increases of temperature from day to day are slightly larger than the decreases. The cold surface layer is rather rapidly destroyed by the increasing wind and re-establishes itself only slowly by prevailing outgoing radiation. The annual trend of the interdiurnal variability is very similar to that found by Simpson for earlier years. The interdiurnal variability of temperature, like the daily range, is greater in winter than in summer. In September, the strongest mean warming occurs, aided by the increase of the mean temperature during this month. The greatest coolings from day to day occur in June and, again, in September. Both warmings and coolings are least in midsummer, December and January. The correlation coefficient of the monthly mean interdiurnal variations with the mean temperatures is -0.8 to -0.9. Table VII also contains the largest temperature changes from one day to the next. The largest rises are generally larger than the largest falls; and, again, the most violent changes of temperature from day to day occur in spring and winter.

The temperature changes from day to day have a considerable persistence. This is shown in Table VIII by the distribution of days per month that belong to a sequence of one or more days with temperature changes in the same sense as compared with the sequences of a random distribution.

Effects of Cloudiness and Wind on Temperature

Clouds have a strong influence upon the temperatures in polar regions. Table IX shows the temperatures on clear days with a mean cloudiness of less than 2/10 and on very cloudy days with more than 8/10 clouds.

A cloud cover diminishes or blocks the effective outgoing radiation, the most important factor in the formation of the cold surface layer. During the sunless period of the year, this blocking tends to raise the temperature. With the exception of the period of continuous sunshine, clear days are markedly colder than cloudy days. Near the ground the temperature differences between clear and cloudy days are not influenced solely by the modified radiation conditions. Wind, strong wind especially, also affects the temperatures.

Table X gives the mean temperatures, irrespective of clouds, under quiet conditions with winds of less than 2 m/sec and under stormy conditions with winds exceeding 22 m/sec. The wind influences the temperatures at shelter level mainly by its influence upon the development of the ground inversion. During the months from May to October, when the ground inversion is strong, the temperatures are much higher with high winds than they are with little or no wind. This rise of temperature with rising wind occurs in spite of the fact that the strong winds come almost invariably from the south where the temperatures on the ice shelf are much lower. This is shown by a comparison of the temperatures at Framheim-Little America and at Bolling Base (Grimminger and Haines, 1939) with those at McMurdo Sound. In March and April, however, the temperature difference between periods of calm and of windy weather is small, because the air on the ice shelf is very rapidly cooled in the autumn, whereas the waters of McMurdo Sound keep the temperature at Cape Evans rather high even within the surface layer. Hence, removal of the surface layer changes the temperature only slightly.

In the summer, November to February, windy days are colder than calm days. During this period the insolation is strong enough to prevent or at least weaken the inversion, while the air that comes with strong winds from the ice shelf is colder than the locally-conditioned air.

The relation between the temperature and the cloudiness, and the wind speed is, however, complicated by the fact shown in Table XI that on the average the wind velocity is considerably stronger on cloudy than on clear days. The cold surface layer will be weaker and more disturbed on cloudy days. To illustrate the relative influence of clouds and wind upon the surface temperatures, the temperatures with clear and with cloudy sky have been grouped according to the simultaneous wind velocities. The result in Table XII suffers from the fact that the number of cases (given in brackets) in some of the subgroups is very small. The observations have been divided into natural seasons: summer, November to February; winter, April to September; and transitional, March and October.

With the same wind speed, the temperatures are, on the whole, lower with clear than with cloudy skies. This does not apply to strong winds in summer. Under these conditions no ground inversion forms and the continuous sunshine with clear sky raises the temperature. With strong winds the difference between the temperatures on clear and on cloudy days is generally small.

The influence of clouds and winds upon surface temperatures can be separated in a more satisfactory way by establishing the regression equations. They have been calculated for the deviations of the daily means of temperature, cloudiness, and wind, from their monthly means. If the temperature t is expressed in °C, the cloudiness c in octas, and the wind W in meters per second, we get the following equations. (The numbers of days are in parentheses.)

June and July	(122)	$\Delta t = +2.25\Delta c + 1.05\Delta W$
October	(62)	$\Delta t = +.079\Delta c + .238\Delta W$
December and January	(57)	$\Delta t = -.600\Delta c - 1.31\Delta W$
April	(60)	$\Delta t = +.623\Delta c + .192\Delta W$

These regression equations show that clouds and wind both raise the temperature considerably in midwinter. This is true for the transitional months of October and April, too, but the effect is much weaker. On the other hand, in midsummer, December and January, the temperature drops strongly when clouds obstruct the solar radiation and when the rising wind brings colder air from the ice shelf.

To compare the relative importance to the temperature of changes in cloudiness and in wind, the deviations Δc and ΔW, the standard deviations of cloudiness and wind, are introduced into the regression equations. (Those of temperature have been added.) They are:

	$\sigma\Delta T$ (°C)	$\sigma\Delta T$ (°C)	$\sigma\Delta W$ (m/sec)
June and July	5.3	2.2	6.55
October	4.1	3.1	6.6
December and January	3.1	2.5	5.0
April	3.7	2.0	6.6

Then the influence of the standard deviation is obtained and, in this way, the influence of the mean deviation of both cloudiness and wind upon the temperature.

The resulting numerical values show that in all months the "normal" changes of the wind modify the temperatures more strongly than the variations in cloudiness. This applies to the cooling with increasing cloud and wind during midsummer as well as to the warming under the same circumstances during the rest of the year. The prevalence of the wind influence is marked in winter, spring, and summer, and small in autumn.

Earth Temperatures

Some measurements of earth temperatures were made at Cape Evans during the summer of 1916, from 17 January to 19 February. The instrument used was an ordinary mercury thermometer buried in the soil at a depth of 4 cm. Table XIII gives the differences between the temperatures of the soil and the simultaneous shelter temperatures.

In midsummer the ground becomes considerably warmer than the air. In view of the absorption of the strong incoming radiation by the soil, this is likely to be the normal condition of the ground as soon as thawing and infiltrations of melt water have proceeded to a sufficient depth into the ground. The few observations indicate that no connection appears between cloudiness and the temperatures excess of the ground. During the summer at Snow Hill (64°22'S, 57°W), an excess of 2.8° at a depth of 30 cm occurs over the air temperature (Bodman, 1908).

TEMPERATURES AT HUT POINT AND IN McMURDO SOUND

During the winter, members of the expedition stayed for some time at Hut Point (77°51'S, 166°45'E), the winter station of Scott's first -- "Discovery" -- expedition. The temperatures were observed generally at about 9 a.m. and 8 p.m. from 5 October to 15 December 1915. The 40 observations during this time show temperatures at Hut Point that were 1.0° higher than at Cape Evans for the same period. Temperature observations had been made in a similar fashion during Scott's second -- "Terra Nova" -- expedition. Simpson (1919), on the other hand, though, found that during the period of his observations -- 148 days in February, March, April, May, September, October, and a few days in November, 1912 -- Hut Point was, on the average, 2.0° colder than Cape Evans. This seems contradictory. However, most of the observations of 1915 were made in the summer, and in 1911 too, on the same dates as those in 1915, the temperatures at Hut Point were higher than at Cape Evans. It is therefore likely that in midsummer Hut Point is indeed warmer than Cape Evans and that the different stations in McMurdo Sound do not differ from each other in their annual average by more than 1°. It would be justifiable then to combine the older observations at Hut Point, Cape Evans, and Cape Royds with those from 1956 to 1961 at Williams Air Facility (77°51'S, 166°38'E) to obtain a temperature series of 8 years on Hut

Point Peninsula and of 11 to 13 years during the half-century 1902-1961 in McMurdo Sound. The series are given in Tables XIV and I.

As already pointed out by Wexler (1959), the observations from the different years show no indication of any progressive temperature change. The variability of the monthly mean temperatures is one and one-half times greater in the winter than in the summer. The variability of the mean annual temperatures is identical with that of the only station south of 60° with a long unbroken record, Laurie Island, Argentina (1951).

TEMPERATURES ON THE ROSS ICE SHELF

Meteorological observations were taken during most of the sledge journeys on the Ross Ice Shelf from its edge to Mt. Hope near the mouth of the Beardmore Glacier (83 1/2°S). The air temperatures were read on a sling thermometer, generally in the morning, at midday, and at night. Altogether, 323 observations are available. They cover the time from the end of January to the end of March, 1915, and from October 1915 to March 1916. For 188 of them, comparable observations exist at Cape Evans, too. As already stressed by Simpson (1919) and Kidson (1930), the temperatures are considerably lower on the ice shelf than at Cape Evans. Table XV shows the differences during different parts of the year. For February and March 1915 no observations from the coast are available because the shore station had not yet been established, and the observations on the ship off Cape Evans are lost. Therefore, the means of these months given for McMurdo Sound in Table I have been used to establish the mean differences between coast and ice shelf. Otherwise, the differences are those between contemporaneous observations. The locations are shown on the map.

Table XV shows a very regular trend in the temperature differences between the coast and the ice shelf; they are large, up to 20°, in autumn and late summer, and small in the middle of summer. Only a small fraction of the temperature difference can be attributed to the higher latitude of the ice shelf. The observed mean temperatures on the ice shelf, with the exception of those in March 1916, are certainly still warmer than the true daily means, because they are derived preponderantly from observations during the warmer part of the day. The temperature differences are in good correspondence with those between the ice shelf and Cape Evans found by Simpson (1919). They are also similar to the following differences between McMurdo Sound and Framheim-Little America (which represents the conditions of the ice shelf notwithstanding its small distance from the open sea):

October 7.0°, November 7.0°, December 3.5°, January 2.5°, February 5.0°, March 7.5° (Meinardus, 1938).

On Table XV the observations between 13 January and 6 February were taken between 81° and 83 1/2°S, but there is no clear indication that the temperatures on the ice shelf continue to decrease strongly as one proceeds south. Most of the temperature difference between coast and ice shelf is concentrated in the northern border region. In mid-March 1916, the ice shelf temperatures taken from the printed log of a sledge journey (Joyce, 1929) were very low. But similar low temperatures have been noted in March in early years (Simpson, 1919, p. 29).

These mean temperatures on the ice shelf, compared with those at the coast, are due mainly to stronger cooling at night, rather than to lower temperatures on the shelf during the day. This is shown in Table XVI by the temperature differences between Cape Evans and the ice shelf at different times of the day. With consistently lower temperatures on the ice shelf, the temperature differences between the two areas are greater in the morning and again in the afternoon, but smaller at midday. This implies that the diurnal temperature variation is greater on the ice shelf than at McMurdo Sound.

Readings on maximum and minimum thermometers were taken during the sledge journeys, mostly during the morning hours. It is presumed that the thermometers were set out at the time of camping and that the readings in the morning refer to the preceding 10 to 12 hours as described by Simpson (1919). For this reason, these shelf temperatures have been compared in Table XVII with the extreme temperatures recorded at Cape Evans between 7 p.m. and 7 a.m. Some readings of extreme temperatures that occurred at Hut Point at the same time have been added.

Between 5 October and 12 December 1915 extreme temperatures corroborate the fact that Cape Evans is slightly colder than Hut Point in midsummer (Table XIV). In all periods, the range between maximum and minimum readings is larger -- one and one-half times or more -- on the ice shelf than at Cape Evans. At Hut Point, too, the daily range is slightly larger than at Cape Evans. The difference between the minimum temperatures of the ice shelf and the minimum temperatures of Cape Evans is considerably larger than that between the maximum temperatures. The larger temperature range on the ice cap is caused mainly by stronger cooling with low sun.

As the differences between the maximum and the minimum temperatures of Table XVII are computed only from observations during the periods of rest on sledge journeys, the true daily range over 24 hours will be considerably larger. At Cape Evans from October to February, the true daily range is 6.7° as against only 5.3° (Table XVII) for the periods that were contemporaneous with the observations of extreme temperatures on the ice shelf. If the range of 8.6° on the ice shelf is increased at the same proportion, the true diurnal range on the ice shelf becomes about 11° C, a satisfactory agreement with the values found by Simpson (1919) during the sledge journeys of Scott's expedition.

PRESSURE

At Cape Evans a mercury barometer and a barograph were used to measure the air pressure. Within the pressure range of the observations, the barometer had no instrumental error. On 5 December 1916, at 3 p.m., the mercury vessel was 4.10 m above the surface of the floating sea ice which was then 25 cm thick. Because at this time water level was about 20 cm below mean sea level, according to the observations of the tides, the height of the barometer above mean sea level was 3.85 mb. This height is so small that a uniform sea level correction of +.50 mb can be applied to all pressure observations irrespective of air temperature. Together with a gravity correction of +2.37 mb, the total correction applied is +2.9 mb. Table XVIII gives the mean monthly pressure reduced to 0°C, sea level, and 45° latitude taken from six readings a day at four-hourly intervals, with the exception of October 1915 with only four readings from 7 a.m. to 7 p.m. In March 1915 and in January 1917, readings were taken for only six to eight days.

The minimum of the monthly pressures occurred in October. The occurrence of the minimum at this time is a common feature in the Ross Sea; it appeared also in the five-year means of McMurdo Sound between 1902 and 1912, and in the three-year means 1911 to 1935 at the eastern side of the Ross Sea. This is remarkable, considering that in the northern polar regions the corresponding month -- April -- has a high pressure. The pressure maximum in August in both years, 1915 and 1916, on the other hand, was not repeated in the other years. Altogether the pressure distribution for 1915-1916 was somewhat irregular. Winter in this period had the second highest pressure of the four reasons (Table XVIII). But in the averages of the earlier five years, winter had had the lowest pressure.

As the daily pressure variation can be based upon four-hourly observations only, no such detailed analyses as those performed by Simpson (1919) and Kidson (1930) are warranted. Table XIX contains the means of the deviations from the monthly means at the different hours of observation.

The mean values for 1916 and for all observations give a clear indication of a twelve-hourly variation which in amplitude and phase corresponds very well with the diurnal variations found by Simpson (1919) and Kidson (1930). The morning minimum at about 5 a.m. and the evening maximum at about 9 p.m. were very marked. As at Cape Royds, the morning maximum in summer was very pronounced; but it was not noticeable in winter. Some other features noted by Simpson at Cape Evans four years earlier do not appear in our observations.

The unperiodic pressure changes can be represented by the interdiurnal variations. Table XX contains the mean monthly interdiurnal variations of the pressure at 11 a.m.

The pressure variation from day to day was about twice as big in winter as in summer. The variability was greater than at other stations near the edge of the Antarctic continent, thus indicating the frequent weather changes at the southern side of the Ross Sea. According to Table XX, in 1915 and 1916 the pressure rises in 24 hours were slightly greater on the average than the pressure falls. Correspondingly, the number of rises per year, 177, was smaller than the number of falls, 189. In view of Table XXI it is unlikely that this represents a normal feature of the pressure at McMurdo Sound. Table XXI contains the mean interdiurnal pressure variations for selected months during six to seven years (van Rooy, 1957) in McMurdo Sound. The rises and falls are of almost the same size. Comparison of the same months in Tables XX and XXI shows that the years 1915 and 1916 had a slightly weaker pressure activity than previous years.

The extreme monthly pressures observed in the four-hourly observations between 25 March 1915 and 7 January 1916 are given in Table XXII. The true values should be slightly more extreme.

With the exception of August, September, and November, the maxima and minima refer to either year, 1915 or 1916. The values with asterisks exceed those observed during the preceding five years of observations. The range between the extreme pressures in the winter months is almost twice that in the summer months because the cyclonic activity influences the Ross Sea area much more strongly in winter than in summer. A comparison of Tables XVIII and XXII shows that in eight out of twelve months, the minima dropped farther below the average monthly pressure than the maxima rose above it. The average deviation of the extreme maxima from the mean of the month was +18 mb. and that of the minima, -22 mb.

WIND

Wind Speed

Complete anemometer records for wind speed and direction are available from 5 April 1915 to 7 January 1917. Table XXIII gives the mean monthly wind speeds in meters per second (m/sec) as derived from six four-hourly observations per day during this time.

These wind speeds agree well with those measured at Cape Evans in 1912, which was the windiest of five earlier years in McMurdo Sound. Compared with the neighboring stations, Cape Evans is in a very windy location. The annual trend at Cape Evans is characterized by weaker winds in midsummer and stronger winds in winter. Although the strong winds of February 1916 are matched by a marked increase in the wind speed from January to February in other years, they are still probably higher than the average of February. In 1916, July and September had stronger mean winds than February. A wind increase in November occurred in both years 1915 and 1916; it is connected with a strong prevalence of southeast winds (Table XXVI).

The monthly and even the annual wind speeds vary considerably from year to year, for the months April to December the mean monthly speed was 8.3 m/sec in 1915, 9.7 m/sec in 1916, 7.0 m/sec in 1911, and 10.0 m/sec in 1912 at Cape Evans.

The frequency distribution of winds of different speeds is given in Table XXIV. It shows an interesting feature -- that of a double maximum. One maximum was with near calm conditions, while the other was with wind speeds around 16-18 m/sec. The second maximum is connected with the blizzard; consequently, it is not well developed in midsummer. The secondary frequency maximum is in the winter months at a higher wind velocity, about 18 m/sec, than it is in the neighboring seasons. Very heavy winds are restricted to the winter half year, whereas winds over 30 m/sec are absent during the summer half year. The last line of Table XXIV gives the wind frequencies in equal steps of one mile per hour.

Table XXV shows the mean frequencies of all days with gale, that is, winds exceeding 16 m/sec, = 8 Beaufort; of the gale-days, the days with strong gale, that is, winds = 22 m/sec, 9 Beaufort; and the fraction of time during which winds are of gale strength. Because the table is based only on observations at intervals of four hours, the true frequency of gales is probably still bigger. At Cape evans gales are frequent. They occur during nearly 2,000 hours in the year, and in the winter half year, during 1,200 hours (three out of eleven observations). There were as many days with gale as there were during earlier winterings at Cape Evans (Simpson, 1919). The values of February, based upon the observations during one year only, are probably abnormally high. As to heavy gales, they can be expected on the average in the winter half year for two hours in twenty-four.

Wind Direction

The wind direction at the Cape Evans station is influenced by Mt. Erebus, which rises immediately to the east of the station, and by the proximity of the Ross Ice Shelf, which stretches to the south of the station. Mt. Erebus channels the wind into certain directions and blocks the wind coming from other directions. The cool air draining off the Ice Shelf has its effect on wind direction. Simpson (1919) discussed these influences in great detail. Table XXVI gives the frequency distribution of winds from the different directions at Cape Evans.

The scarcity of winds from a westerly direction, a common feature of all observations at McMurdo Sound, is surprising. Simpson (1919) attributes it mainly to the sheltering effect of the big mountain range of Queen Victoria Land to the west. But this range is 30 to 40 miles away, and in similar situations elsewhere, the wind flow is not impeded to the same degree. In fact, during sledge journeys on the western side of McMurdo Sound and nearer to the Western Mountain Range, westerly winds have been more frequent (Simpson, 1919). In some cases they might be due to the outflow along the west-east valleys of the mountain range rather than to a general flow from the west. Possibly, immediately to the east the huge Erebus massif deflects the westerly winds upwards and away from its western base.

The resultant wind direction at Cape Evans is southeast to east. The stability, not considering the wind speed, is 65 per cent. As the most frequent winds are at the same time the strongest, the stability of the mean vector wind will be even higher. A rough estimate, extrapolated from the velocity distribution of the different directions, according to Simpson (1919), gives a stability of not less than 75 per cent. The last column of Table XXVI shows the percentage distribution during 1916. They are even more concentrated in the southeast quadrant than all other winds. A close study of individual cases reveals that the direction of the gales is almost invariably between southeast and east-southeast. As Simpson (1919) has already noted, in 1916, too, the direction of the strongest winds was slightly more from the east than the mean direction of all gales. This is, according to Simpson, a local effect due to the deflection of the airflow by Mt. Erebus.

Generally strong winds at Cape Evans are contemporaneous with strong winds on the ice shelf. However, the gales on the ice shelf are frequently from a more southerly direction. There are some cases when blizzards existed at one place but not at the other, and there is the exceptional case of 21-22 January 1916 when Cape Evans had a strong wind from the southeast, while on the ice shelf near 83°S the winds were moderate from the north.

Diurnal Wind Variation

Most of the time, the winds at Cape Evans have a marked diurnal variation. At the different hours of observation for the period of 22 months, 1915-1917, the average wind speeds are in Table XXVII. The means have been corrected for different speeds at the beginning and the end of the month.

In all seasons we find a maximum of wind speed in the afternoon and a relatively low wind velocity during the morning hours. This is the only variation during the summer months, with the exception of a maximum in February at 3 a.m., which was, however, based upon observations of only one month and probably does not represent average conditions. In McMurdo Sound during the months with little or no sunshine (April to August), Kidson (1930) has claimed that the daily variation of the wind is related to that of the pressure with a coefficient of correlation of -0.8 between the two. For four years, Simpson (1919) finds a correlation of -0.55, which may be significant. But the two years under consideration do not fit into this pattern, and it is doubtful whether there is actually a causal connection between the daily variations of pressure and of wind speed, of the reality of which Simpson, too, is not convinced. It has further been considered whether or not the daily wind variation is also in winter, as in summer, in phase with the daily temperature variation; but no connection exists.

The normally stronger winds in the afternoon and the lower mean wind speed in the morning suggest a higher frequency of very light winds and calms in the morning. Table XXVIII gives the diurnal distribution of calms for the year and the seasons which corresponds to the diurnal variation of the mean winds. The least number of calms is during the afternoon hours. They occur most frequently shortly before midday in the winter, and during the early morning hours in the summer. This completely reflects the influence of solar radiation upon the ground layer below the inversion. It is remarkable that the afternoon minimum of very weak winds is found also during the period with no sunshine, May to July.

Upper Air Motion

The air motion at Cape Evans at and above 14,000 ft can be determined when the smoke issuing from the summit crater of Erebus is visible. Table XXIX gives the annual mean of the direction of the plume for 1915 and 1916. There are some cases in which the plume indicated a definite change of direction with height. In these cases the direction at the lowest point on the plume has been used.

The first line gives the percentage frequency of all observations of Erebus smoke. In this case, days with weather favorable for the observation of the summit have been weighted too heavily. Hence, in the second line the sum of all observations on the same day has been given the weight one, the individual observations each getting the same fractional weight. The resultant direction of the smoke plume is S. 83° W. This agrees excellently with the observations at Cape Evans in 1911-1912, when Simpson (1919) found a resultant wind from S. 82° W. Observations at Hut Point 1902-1903 and at Cape Royds 1908 give higher frequencies of southwest winds. It is possible, however, that at Cape Evans the number of observations of winds from the southwest is too low. Cape Evans lies just southwest of the summit of Erebus, and, as Simpson realized, with strong winds from the southwest the smoke plume might be hidden by the mountain. The stability of the flow is 19 per cent, and the percentage distribution of the motion in the principal directions is: north, 29 per cent; south, 30 per cent; east, 13 per cent; and west, 28 per cent.

One thus finds the interesting result that at the four to five km height of the Erebus smoke plume, the meridional components of the air motion are of the same magnitude as the zonal components. At this height all available observations from McMurdo Sound show that the exchange of air between sub-Antarctic and high-Antarctic latitudes is quite strong. The same applies to Little America, where in 1929-1930, 1934-1935, and 1940-1941, the flow at 500 mb, slightly below 5 km, was prevailingly from the north during summer and autumn, and from the south in the other seasons, whereas the resultant mean annual transport of air was from the west (Grimminger and Haines, 1939). The Erebus, plume, too, shows prevailing wind from the west.

HUMIDITY

Humidity of the Air

At low temperatures the atmosphere can hold only small amounts of water vapor, the measuring humidity becomes very difficult. Neither the dry and wet bulb thermometers nor the hair hygrometer are satisfactory, and many Antarctic expeditions abandoned observations of humidity or did not evaluate those made (Simpson, 1919). At Cape Evans a hair hygrograph was in continuous operation during 1915-1917. Towards the end of the expedition its reading was obviously too high, for it had recorded several cases of humidities in excess of 100 per cent. As a whole, however, the hygrometer observations seems reliable. In any case, they are in good agreement with other, also somewhat doubtful, observations from the Antarctic, particularly those at Little America (Meinardus, 1938). In Table XXX the monthly means of relative humidity for the different hours of observations are given. All relative humidities refer to saturation with respect to water.

During the winter months, May to October, the mean humidity content of the lowest layers corresponds almost exactly to the equilibrium pressure in contact with a surface of ice at the mean monthly temperatures, the relative humidity of which is shown in the last line of Table XXX. Midsummer, December and January, has a marked diurnal variation with the highest relative humidity occurring during the night, and the lowest, in the midday hours. During the summer the water vapor pressure, also, has a daily variation corresponding to that of the temperature. As Table XXXI shows, it is slightly higher during the midday than during the night hours.

In the winter, May to July, when the sun is permanently absent, relative humidity is at a minimum at 11 p.m. which coincides with a temperature maximum at that hour. The connection shown in Table XXXII may be significant; it would result if the vapor pressure remained unchanged.

Although the average relative humidities are high, there is, nevertheless, an appreciable number of cases when they become lower than 45 per cent and occasionally as low as 25 per cent. These low humidities are almost invariably connected with temperatures considerably higher than the average of the month and frequently with strong winds.

Such low relative humidities over a surface almost completely covered by water, snow, and ice can be brought about in two ways. A layer of water vapor at -30° near the ground is in equilibrium with an ice surface and, hence, has a relative humidity of 75 per cent. This layer, 200 m thick, is overlain by air with a temperature eight degrees higher. To have equilibrium of water vapor pressure at the border of the two layers, the relative humidity of the overlying air must be as low as 36 per cent. In winter such a structure of the atmosphere is by no means unusual. If the wind removes the cold ground layer, the air of -30° and 75 per cent relative humidity will, excluding mixing processes, be replaced by air that has been slightly heated during the descent, and has a temperature of -20° and a relative humidity of 30 per cent. Thus, low relative humidities can be brought about by removal of the cold ground layer alone.

The other possibility is the foehn effect, adiabatic heating of descending air. Because the Mt. Erebus mass, with a summit near 4000 m, lies towards the northeast from Cape Evans, winds from this sector are likely to get a descending component and become in this way warm and relatively dry. In fact, the rare strong winds from the northeast quadrant are five degrees warmer, with a relative humidity 30 per cent lower than the average. The last fact at least suggests a descending air motion. In one case, they remarked that the Erebus smoke was carried downwards by a strong northeast on 14 April 1915. In another case, one of low humidity, 20 March 1916, the observer noted that winds descending from Erebus brought a strong load of kenyte from the mountain slopes.

Besides the hygrograph records, a number of dry and wet bulb observations have been made. They are not in good agreement with simultaneous readings of the hair hygrometer. Similar discrepancies have been noted during other Antarctic expeditions. As a whole, the hair hygrometer seems the more useful instrument, at least when dealing with temperatures above -30°. At low temperatures the hair becomes very sluggish, but it still gives the mean of the relative humidity over a lengthy period. The differences between dry and wet bulb thermometer readings become very small at low temperatures; therefore, close measuring, generally impossible to do, would be necessary to determine the humidity. At Cape Evans the wet bulb thermometer read frequently higher than the dry bulb. This can occur if the wet bulb is covered by ice and if the water vapor pressure in the atmosphere exceeds, as frequently happens, the equilibrium pressure in contact with an ice surface. Nevertheless, in view of the great discrepancies, the humidity observations with the dry and the wet bulb thermometers will not be discussed.

Evaporation

It has been found repeatedly (David and Priestly, 1914; Wright and Priestley, 1922) at McMurdo Sound, as well as at other places in the Antarctic, that the evaporation can be considerable, notwithstanding the low temperature and generally high relative humidity. In order to measure the evaporation from a horizontal ice surface, in 1915 and particularly in 1916 very exact measurements were made on three stakes frozen into the ice of a small lake northeast of the winter hut. Fortnightly readings of the ice level were taken. The observations can be divided into two groups, those made during the time when no possibility of thaw existed and those made when the daily maxima exceeded -10°, at which temperature traces of melting can be noticed. Ablation by mechanical erosion can probably be discounted as a means of removal; the loss of material is due entirely to evaporation. In 1915 observations were made from 24 July to 25 September, and in 1916 from 19 April to 16 November. The ablation is shown in Table XXXIII.

The correspondence between the fortnightly amounts of evaporation and the mean temperatures is very good. For the period 19 April to 12 October the coefficient of correlation between 12 ablation readings and the mean temperatures is +.87; for the whole period 19 April to 16 November with 15 observations, it is still +.84. As with rising temperatures, evaporation increases at a higher than linear rate, the logarithms of the evaporation have also been correlated with the simultaneous temperatures; the coefficient of correlation turns out to be +.95, a very high value.

The close correlation between temperature and rate of evaporation may have two reasons. Firstly, and principally, the possible maximum amount of water vapor in the atmosphere and hence of possible evaporation decreases very strongly with decreasing temperature. With the mass of water vapor at 0° as unity, the mass of a volume of water vapor saturated with respect to ice is for the different temperatures:

°C	0	-10	-20	-30	-40	-50	-60	-70
	1.000	.447	.184	.070	.026	.008	.0023	.0006

Hence, at low temperatures the evaporation can be only very small. Secondly, under the conditions of Cape Evans, high temperature is most often connected with strong winds and, as the winds contribute to the evaporation, for this reason, too, higher temperatures will be accompanied by stronger evaporation. The data are not sufficiently numerous to separate the influences of temperature and of wind upon the evaporation.

The observations of evaporation at Cape Evans are of special interest because they provide some information about the rate of evaporation on the ice cap itself. Starting from the evaporation measured at a temperature of -25° -- 0.02 mm/day -- the evaporation at other temperatures is extrapolated in the proportion of the equilibrium pressure in contact with ice at these temperatures to that at -25°. To represent the situation for average ice cap conditions, the monthly temperatures at a height of 2500 m and at a latitude of 76°S are chosen. The result is an annual evaporation of at best a few millimeters of ice, almost exclusively during the midsummer months. The evaporation over the inner parts of the Antarctic ice cap is an order of magnitude smaller than the accumulation. For the same reason -- a very small gradient of humidity because of the low temperatures -- the direct deposition of hoarfrost on the ice cap must be very small. The removal of drifted snow over the whole interior of the ice cap is also small. Hence, in first approximation, the accumulation can be equated with the precipitation.

Other studies were made of the evaporation loss of ice blocks of different sizes and weights which were put on the snow. The exposure lasted from 30 December 1916, 8 p.m., to 1 January 1917, 8 p.m. The mean temperature during the experiment was -6.0°, the highest temperatures was -2.0°, the relative humidity 89 per cent, and the wind at anemometer level 10 m/sec. In excellent correspondence with each other, the blocks of about 14-cm-side length that were kept in the shade, showed a loss of .05 mm per hour. The value is obviously bigger than the loss from a natural, nearly horizontal surface.

CLOUDS

During the whole period at Cape Evans, careful and extensive observations of clouds were made. Simpson (1919) discussed at length the difficulties of determining the type of cloud and the amount of cloudiness under polar conditions during the periods of darkness. The latter difficulty has the consequence that in winter the observed cloudiness is too low, particularly as a thin structureless cover that allows the brighter stars to be seen, occurs quite frequently in polar regions. Table XXXIV gives, in octas, the mean cloudiness of different months.

The observed average cloudiness agrees well with previous observations at Cape Evans. Cloudiness was rather high as it is everywhere near the coasts of the Antarctic. Of the nine available months of 1915, seven are less cloudy than the corresponding seven months of 1916, the mean difference for all months being 1.1/8. Notwithstanding the difficulties of observing and the changes of observers, the differences is likely to be real. Except in midsummer, clouds raise the temperature. As shown in Table I, most of the available months were colder in 1915 than the corresponding months in 1916. The coefficient of correlation of the differences in cloudiness and in temperature during the months April to October of both years exceeds +0.8, thus indicating a close connection.

Table XXXIV contains further the number of clear days per month with an average of cloudiness less than 1.6/8, and of very cloudy days with more than 6.4/8 cloud cover. Clear days represent 15 per cent, dull days 36 per cent of all days.

In Table XXXV the cloudiness conditions are represented in still more detail by the percentages of the frequencies of the different degrees of cloudiness. It should be noted that in this table cloudiness is represented by the eleven-step scale of the original observations, whereas the data in Table XXXIV have been converted to the new scale of nine steps. The monthly percentage values have been calculated from all observations made during a given month. Without the different numbers of observations in individual months being taken into consideration, the frequency distributions of the seasons are the means of the percentages of the constituent months.

The normal double-peaked frequency curve of cloudiness with frequent occurrences of either completely or nearly cloudlessness, or completely or nearly overcast, sky and rare occurrences of clouds covering about half the sky, exists at Cape Evans, too. The greater frequency in autumn and winter of days with little or no clouds is probably not significant; in darkness clouds near the horizon remain frequently undetected. From October to February the sun is at no observation time even as much as -8^{o} below the horizon and the observations are unimpeded. The last line of Table XXXV shows, as is expected, that under these circumstances cloudless sky is less frequent and high cloudiness more frequent than for the average of the whole year. These percentages are probably near to the true average distribution.

An effort has been made to establish the diurnal variation of cloudiness. This is possible only during the months October to February, when daylight is permanent at all observation times. The observations of Table XXXVI give slightly greater cloudiness at 11 a.m., 3 p.m., and 7 p.m., than during the other hours. This result is reasonable and is corroborated by the data for 1911-1912 in Table XXXVI. Even in Antarctic latitudes, the heating during the warmer part of the day favors the formation of clouds in the summer. However, no correspondence has been found between the daily variations of cloudiness during the months of complete darkness, June 1915 and 1916 on the one hand, and 1911 and 1912 on the other.

The observers at Cape Evans made very extensive and detailed observations of cloud types in which is hidden a wealth of information that cannot be analyzed here. In particular, the whaleback clouds near Erebus and over the Western Mountains across McMurdo Sound are frequently mentioned. They persisted sometimes for several days. These clouds are connected with standing waves caused by the orographic conditions.

The direction of the motion of the clouds was recorded often. As most of the observations refer to the lowest clouds, motion from southeast and south is very preponderant. It is noticeable, however, that the movement of the low clouds is often more directly from the south than the simultaneous surface wind.

The observations of medium and high clouds corroborate the fact already established from the observations of the Erebus smoke, that the meridional components of the air motion are quite strong. Just as during Shackleton's first expedition, cloud motion from the north and the south was more frequent than zonal motion. The cloud motions indicate a strong exchange of air between the Antarctic continent and the Ross Sea. The resultant direction of the upper wind as revealed by the motion of 77 alto and cirro clouds is from east to south, but the stability of the motion is only 15 per cent. It is, however, uncertain whether or not this represents the true mean wind at these levels.

TIDES

During the wintering at Cape Evans, some records of the tides were made from 30 October 1916 to 5 January 1917. For most of the period, four-hourly readings and maximum and minimum values during periods of four hours are available. From 12 to 30 November, hourly observations were taken. The tides in McMurdo Sound had been previously recorded by the "Discovery" (Darwin, 1908) and the "Terra Nova" (Doodson, 1924) expeditions under Scott, and by Shackleton's expedition in 1908-1909 (Darwin, 1910). Later tide observations have been published recently (Macdonald and Burrows, 1959). The observations during 1916-1917 are in very good agreement with those found at other times, and no detailed discussion is necessary.

The diurnal components of the tide prevail over the semidiurnal components; the latter become directly noticeable only at neap tide. As the fraction $F = (K_1+O_1)/(M_2+S_2)$ equals 2, the tides at Cape Evans are found to be of the mixed, prevailing diurnal type (Dietrich, 1944). With the exception of the days near neap tide, high tide occurs shortly after midnight and low tide around midday, which is eleven hours ahead of world time. The spring tides have an age of one or two days. The proportion of the amplitudes of spring tide to neap tide, comprising the three highest and three lowest tides, is 3.0. During the period of the observations, the spring tides at new moon were bigger than those at full moon. The rise of the tide is slower than the fall; flood tide lasts on the average 13 hours, whereas ebb tide lasts 11 hours.

Because the reduction factor for the recorded tidal heights is not available, an indirect method had to be used to establish approximately the actual oscillations of sea level. The variations of the mean daily sea level are closely related to those of the air pressure. For one lunar month of 27 days, from 7 December 1916 to 3 January 1917, the correlation of the daily means of sea level to air pressure was -0.86. For 25 July to 22 August and 15 November to 12 December 1911, and 29 December 1911 to 26 January 1912, the coefficient for these 87 days was -0.75 (Doodson, 1924). This close parallelism between pressure variations and sea level changes is corroborated by experiences from the northern hemisphere. From the known concurrent changes in daily mean pressure and mean sea level, a reduction factor can be found that can then be used to transform the relative data for the tides to absolute height values. The mean difference found when the mean daily pressures are subtracted from the monthly average is 0.184 inches of mercury in December 1916. This corresponds to 2.44 inches of sea water. The mean difference between the mean daily sea level and the monthly average in December 1916 is equal to 0.170 relative units. Supposing that the 0.170 units correspond to 2.44 inches of water as suggested by the high correlation of the mean daily variations of sea level and air pressure, we get the reduction factor 2.44/0.170 = 14.3.

This reduction factor can then be applied to the relative units in which the tidal variations of sea level have been recorded. The range between the two highest and two lowest water levels during the month of December is about 3.5 units. This then corresponds to a range of 50 inches or 4 feet 2 inches. During December 1957, at Williams Air Facility, on the south side of Hut Point Peninsula, the range was 4 feet 3 inches (Macdonald and Burrows, 1959). Doodson (1924) finds at Cape Evans in December 3 feet 9 inches as the sum of the amplitudes of the four biggest partial tides. There is then a very satisfactory agreement between the observations in other years and the values for 1916, when a reduction factor of 14.3 is applied; this suggests the reliability of the method of calibration used.

REFERENCES CITED

Argentina. Ministerio de Asuntos Tecnicos. Servicio Meteorológico Nacional (1951). Datos climatológicos y geomagnéticos. Islas Orcadas del Sur, (lat: 60°44' S - long: 44° 44' W) periodo 1903 - 1950. Buenos Aires. Series B. 1. seción. 1. parte. No. 11, 97 p.

Bodman, G., 1908, Wissenschaftliche Ergebnisse der Schwedischen Südpolarexpedition, 1901-03, vol. II, part 2: Generalstabens Litografiska Anstalt, Stockholm, 364 p.

Brooks, C. E. P., 1917, The reduction of temperature observations to mean of 24 hours: Royal Meteorol. Soc. Quart. Journ., vol. 43, p. 375-388.

Dalrymple, P. C., 1961, South Pole micrometeorological program, Part I, Data presentation: Quartermaster Research and Engineering Center, Earth Sciences Division, Techn. Report ES-2, Natick, 392 p.

Darwin, G. H., 1908, Tidal observations of the "Discovery" National Antarctic Expedition 1901-04; Physical observations: Collected Papers, vol. I, p. 373-388.

_______, 1910, The tidal observations of the British Antarctic Expedition, 1907: Royal Soc. London Proc., Ser A, vol. 84, p. 403-422.

David, T. E. and Priestley, R. E., 1914, Glaciology, physiography, stratigraphy, and tectonic geology of South Victoria Land: _in_ British Antarctic Expedition 1907-09, Reports of Scientific Investigations, Geology, vol. 1, London, 319 p.

Jack, A. K., unpublished diaries, 23 February to 19 March 1916: in library of Scott Polar Research Institute, Cambridge, England.

Dietrich, G., 1944, Die Gezeiten des Weltmeeres als geographische Erscheinung: Zeitschr. Ges Erdkunde, Berlin, p. 69-85.

Doodson, A. T., 1924, Tidal observation, Miscellaneous Data: _in_ British (Terra Nova) Antarctic Expedition 1910-13, Harrison and Co., London, p. 68-73.

Grimminger, G. and Haines, W. C.,1939, Meteorological results of the Byrd Antarctic Expeditions: Monthly Weather Review, Suppl. 41, 377 p.

Joyce E. E. M., 1929, The South Polar trail: Duckworth, London, 220 p.

Kidson, E., 1930, Meteorology: in Reports on the scientific investigations British Antarctic Expedition 1907-09, Government Printer, Melbourne.

Loewe, F., 1961a, Weiteres über den Firnstoss: Zeitschr. f. Gletscherkunde und Glazialgeologie, vol. 4, p. 227-228.

_______, 1961b, On melting of fresh water ice in sea water: Journal of Glaciology, vol. 3, p. 1051-1052.

Macdonald, J. P. and Burrows, A. L., 1959, Sea level recordings at Scott Base, Antarctica, 1957: New Zealand Journal of Geology and Geophysics, vol. 2, p. 297-314.

Meinardus, W., 1938, Klima der Antarktis: in Köppen und Geiger, Handbuch der Klimatologie, vol. IV, part U, Berlin, Borntraeger, 133 p.

Mossman, R. G., 1921, Meteorological results of the Shackleton Antarctic Expedition, 1914-17 (Weddell Sea Party), Preliminary notice: Royal Meteorol. Soc. London Quart. Journ., vol. 47, p. 63-70.

Richards, R. W., 1962, Marooned in the Antarctic: Scott Polar Research Institute, Occasional Paper No. 2, Cambridge, England.

Shackleton, E., 1919, South, The story of Shackleton's last expedition: Macmillan, London, 374 p.

Simpson, G. C., 1919, Meteorology, Volume I, Discussion: in British (Terra Nova) Antarctic Expedition, 1910-13, Thacker, Spink and Co., Calcutta, 326 p.

van Rooy, M. D., editor, 1957, Meteorology of the Antarctic: South African Weather Bureau, Department of Transportation, 240 p.

Wexler, H., 1959, A warming trend at Little America: Weather, vol. 14, p. 191-197.

Wordie, J. M., 1921, The Ross Sea drift of the "Aurora" in 1915-16: Geographical Journal, Vol. 58, p. 219-224.

Wright, C. S. and Priestley, R. E., 1922, Glaciology: British (Terra Nova) Antarctic Expedition, 1910-13, Harrison and Sons, London, 488 p.

APPENDIX

TABLE I. MEAN MONTHLY TEMPERATURES AND EXTREME DAYS, °C, NEGATIVE, CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1915	—	—	—	17.2	22.1	22.2	25.3	21.1	21.9	17.6	11.4	4.5	—
1916	5.7	4.5	9.8	15.9	23.2	18.5	18.9	23.6	21.9	16.2	8.3	4.3	14.2
Mean 1915–17	6.5	4.5	10.8	16.6	22.6	20.4	22.1	22.4	21.9	16.9	9.8	4.4	14.9
Warmest day	1.7	1.8	1.9	5.9	10.8	8.0	10.7	7.5	12.3	7.4	2.0	1.0	1.0
Coldest day	14.1	9.2	18.8	26.3	31.2	28.6	35.8	33.3	33.8	26.2	16.4	8.5	35.8
McMurdo Sound 11–13 years	4.3	8.4	16.2	21.2	23.1	23.7	25.7	26.6	23.4	19.1	9.4	4.2	17.1

TABLE II. MEANS OF DAILY TEMPERATURE EXTREMES, 1915–17, CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean max.	− 2.8	− 1.5	− 7.1	−13.1	−18.9	−16.0	−18.5	−17.5	−12.4	−12.9	− 6.4	− 1.6	
Mean min.	− 9.2	− 8.1	−13.6	−20.6	−26.6	−24.6	−26.2	−27.1	−26.9	−21.2	−13.5	− 7.2	
Mean range	6.4	6.6	6.6	7.3	7.6	8.8	7.5	9.6	9.4	8.2	7.1	5.7	7.5
Extreme max.	+2.6	+1.1	+1.2	3.0	6.7	2.6	7.9	4.4	9.3	2.7	+2.3	+2.1	+2.6
Extreme min.	−15.6	−13.6	−22.2	−28.6	− 6.6	−32.8	−38.5	−37.2	−27.2	−31.7	−19.9	−11.6	−38.5
Extreme range*	18.2	14.7	23.4	25.6	29.9	30.2	30.6	32.8	27.9	29.0	22.2	13.7	41.1
Extreme 24 hr. range	12	12	12	17	19	19	21	20	22	16	12	9	

*The underlined extreme monthly ranges occurred in the same year.

TABLE III. DAYS EXCEEDING 0° C.

	Jan	Feb	Mar	Nov	Dec
1915-17	10	8	2	2	7
Cape Royds 1908-09	15	7	1	4	24
Cape Evans 1911-12	2	1	0	0	3

TABLE IV. MINIMUM SHELTER TEMPERATURES MINUS TERRESTRIAL MINIMUM TEMPERATURES, 1915-1916, CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7 p.m. to 7 a.m.	--	--	--	--	4.1	5.0	4.2	3.9	4.1			
7 a.m. to 7 p.m.	--	--	--	--	4.2	4.7	4.2	4.2	3.7			
7 a.m. to 7 a.m.	-.9	-.3	1.4	1.6	4.2	5.3	4.7	4.1	4.1	5.7	(1.-10.)	-.6

TABLE V. DIURNAL INEQUALITIES OF TEMPERATURE IN /100°, 1915-1916, CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
3 a.m.	-116	- 4	-26	-11	2	8	- 4	-13	6	-138	-148	-107	-49
7 a.m.	- 6	-34	-34	6	-19	- 1	-39	4	-29	- 33	- 35	- 30	-21
11 a.m.	115	60	18	22	- 9	31	-22	4	41	90	107	60	43
3 p.m.	116	63	58	- 4	13	-27	16	- 9	11	116	107	116	48
7 p.m.	16	6	11	11	-13	-18	33	1	-23	51	35	37	12
11 p.m.	124	-49	-27	-23	25	8	15	14	- 5	-93	-65	-77	-33
Comb. Ampl. 1915+16, °C	--	--	--	0.6	0.4	0.6	0.7	0.3	0.7	2.5	2.6	2.2	1.2
Mean Ampl. °C	2.4	1.1	0.9	0.7	0.6	0.7	1.1	1.0	1.0	2.5	2.7	2.2	1.4

TABLE VI. MEAN MONTHLY REDUCED TEMPERATURE RANGE, AT CAPE EVANS AND AT McMURDO SOUND

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1915-16	4.3	5.5	5.6	6.6	7.1	8.0	6.6	8.6	8.0	5.5	4.5	3.5	6.1
McMurdo Sound 7 years	4.2	5.0	6.0	7.3	7.8	8.8	8.5	9.1	8.8	6.3	4.9	4.1	6.7

TABLE VII. INTERDIURNAL TEMPERATURE VARIATIONS OF DAILY MEAN TEMPERATURES, APRIL 1915-DEC. 1916, CAPE EVANS

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Increases	n	17	13	17	23½	23	30	29½	26	30	32	38½	32	320½
	°C	1.4	1.6	1.7	2.1	3.5	2.5	3.0	2.9	3.6	2.6	1.6	1.1	2.3
Decreases	n	22	16	19	27½	39	30	32½	36	30	30	21½	30	333½
	°C	1.1	1.4	1.8	2.9	1.9	3.1	2.8	2.6	3.0	2.4	1.7	1.1	2.2
Mean, °C		1.3	1.5	1.8	2.5	2.5	2.8	2.9	2.8	3.3	2.5	1.6	1.1	2.28
Biggest rise, °C		7.1	6.3	4.4	6.9	10.2	6.8	11.7	7.1	15.3	9.1	5.4	2.7	
Biggest fall, °C		3.7	3.6	4.1	6.1	5.4	7.4	6.8	6.4	6.6	7.6	4.3	4.2	

TABLE VIII. SEQUENCES OF DAYS WITH THE SAME TEMPERATURE TREND, 1915-1916, CAPE EVANS

Sequence days	1	2	3	4	5	6	7	8
days per month	8.1	8.4	6.2	2.1	2.7	0.9	1.7	0.4
days, random distrib.	15.3	7.7	3.8	1.9	1.0	0.5	0.2	0.1

TABLE IX. TEMPERATURES ON CLEAR AND CLOUDY DAYS, 1915-17, CAPE EVANS

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
clear	n	8	5	7	15	28	26	17	39	19	12	11	11	201
	°C	-4.3	-4.7	-8.5	-18.0	-24.9	-22.8	-28.3	-23.8	-23.7	-16.9	-8.0	-3.4	-15.7
cloudy	n	23	18	21	29	17	19	34	12	28	37	31	29	298
	°C	-7.3	-4.5	-5.7	-15.9	-19.8	-17.7	-19.7	-21.5	-20.5	-16.2	-9.0	-4.9	-13.6
cloudy-clear		-3.0	-0.2	2.8	2.1	5.1	5.1	8.6	2.3	3.2	0.7	-0.4	-1.5	2.1

TABLE X. WIND AND TEMPERATURE, 1915-1917, CAPE EVANS

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
wind<2 m/sec	n	30	7	19	23	80	60	54	102	61	61	27	34	558
	t	-3.3	-3.4	-15.1	-16.0	-28.6	-21.4	-26.8	-25.5	-25.0	-17.5	- 9.3	- 3.1	-16.2
wind>22 m/sec	n	6	13	14	34	27	31	56	18	52	13	12	6	282
	t	-12.8	-4.8	-13.0	-16.4	-18.4	-19.2	-17.5	-18.2	-16.1	-14.2	-13.0	-7.3	-14.2
Δt		- 9.5	-1.4	2.1	- 0.4	10.2	2.2	9.3	7.3	8.9	3.3	-3.7	-4.2	2.0

TABLE XI. WIND SPEEDS ON CLEAR AND CLOUDY DAYS, 1915-1917, CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
clear m/sec	4	7	8	9	5	7	5	6	7	6	5	7	6.5
cloudy m/sec	9	14	11	11	12	9	15	11	13	10	12	9	11.5
cloudy-clear	5	7	3	3	7	2	10	5	6	4	6	2	5.0

TABLE XII. TEMPERATURES IN RELATION TO WIND AND CLOUDINESS, 1915-1917, CAPE EVANS
(numbers of cases in brackets)

cloud		m/sec 0- 2.2	2.4 - 13	≥ 14	Mean
0-2/10	Nov.-Feb.	- 7.0 (11)	- 5.5 (13)	- 2.0 (3)	- 5.7 (27)
8/10-10/10		- 4.0 (9)	- 6.0 (53)	- 8.0 (38)	- 6.6 (100)
0-2/10	March & Oct.	-18.5 (2)	-14.5 (17)	-14.0 (2)	-14.8 (21)
8/10-10/10		-18.0 (10)	-14.0 (30)	-12.0 (16)	-14.1 (56)
0-2/10	April-Sept.	-25.0 (55)	-22.0 (58)	-17.0 (24)	-22.3 (137)
8/10-10/10		-21.0 (24)	-19.5 (43)	-17.0 (65)	-18.5 (132)
0-2/10	Year	-21.3 (68)	-18.1 (88)	-15.2 (29)	-19.1 (185)
8/10-10/10		-16.7 (43)	-12.5(126)	-13.5 (119)	-13.5 (288)

TABLE XIII. TEMPERATURE DIFFERENCE, SOIL MINUS SCREEN, 1916, CAPE EVANS

	7 a.m.	7 p.m.	Jan	Feb	All
n	17	19	18	20	38
Δt	4.1	5.0	7.4	2.1	4.5

TABLE XIV. MEAN TEMPERATURE, HUT POINT PENINSULA, 1901, '02, '56-'61

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Hut Point Peninsula	-3.8	-9.1	-17.5	-22.2	-23.6	-24.6	-26.5	-28.3	-24.0	-20.6	-9.2	-3.8	-17.8
Mean Var. H.P. Peninsula	1.1	1.7	2.0	2.2	1.9	1.1	3.1	1.9	2.1	1.5	0.8	1.1	0.73

TABLE XV. TEMPERATURE DIFFERENCES CAPE EVANS MINUS ICE SHELF

Period	Feb. 1915	March 1915	Oct. 1915	6-20 Nov. 1915	27 Nov.-7 Dec.1915	14-28 Dec. 1915
Location	edge-bluff	edge-bluff	edge-bluff	edge-bluff	edge-bluff	edge-bluff
n	145	55	42	33	27	20
t shelf	-14.4	-25.6	-23.8	-17.1	-7.2	-6.7
Δt	(6)	(10)	8.3	4.9	3.6	2.5

Period	29 Dec. 1915-11 Jan.1916	13 Jan-6 Feb.1916	8-16 Feb. 1916	9-18 Mar. 1916
Location	bluff - 81° S	81° S - 83½° S	81° S - bluff	40 miles to edge
n	23	24	8	8
t shelf	-4.1	-10.3	-11.5	-35
Δt	1.5	5.7	7.1	20

TABLE XVI. DIURNAL TEMPERATURE DIFFERENCES, CAPE EVANS MINUS ICE SHELF, 1915-1916

		10-27X	6-20XI	27XI-7XII	14XII-27XII	29XII-11I	13I-16II	Mean
Morning	n	15	12	11	10	11	—	59
	t	10.1	6.0	4.8	2.8	2.1	—	5.6
Midday	n	—	10	6	—	8	4	28
	t	—	4.0	1.9	—	1.1	4.6	2.8
Afternoon	n	12	12	10	5	9	4	52
	t	7.9	4.1	3.2	2.4	0.3	5.6	4.1

TABLE XVII. CONTEMPORANEOUS MAXIMA AND MINIMA AT CAPE EVANS AND HUT POINT OR ROSS ICE SHELF

Period	n	Max	Min	Max-Min	Max	Min	Max-Min	ΔMax	ΔMin
		Hut Point			Cape Evans				
5X-24XI '15	27	- 9.5	-16.2	6.7	-11.1	-17.3	6.2	-1.6	-1.1
5XII-12XII '15	9	- 1.8	- 8.0	6.2	- 4.2	- 8.4	4.2	-2.4	-0.4
		Ice Shelf							
10X-27X '15	17	-20.2	-30.2	10.0	-14.9	-20.5	5.6	5.3	9.7
7XI-7XII '15	20	- 9.1	-19.3	10.2	- 6.9	-12.6	5.7	2.2	6.7
14XII-29XII '15	12	- 4.7	-11.0	6.3	- 3.0	- 6.9	3.9	1.7	4.1
30XII '15-19I '16	18	- 2.8	-10.9	8.1	- 1.7	- 5.8	4.1	1.1	5.1
20I-5II '16	12	- 8.4	-15.6	7.2	- 4.7	-10.1	5.4	3.7	5.5
6II-16II '16	9	-10.4	-16.2	5.8	- 2.6	- 8.3	5.7	7.8	7.9
Mean	88	- 9.4	-18.0	8.6	- 5.9	-11.1	5.3	3.5	6.9

TABLE XVIII. MEAN MONTHLY SEA LEVEL PRESSURES (mb) CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Range
1915	(991.4) (1917)	--	(983.1)	996.8	1002.4	996.3	990.2	1004.7	994.5	985.6	995.5	992.9	--	(19.1)
1916	990.1	994.2	992.6	990.9	994.2	990.5	983.6	994.6	981.6	980.4	990.8	993.8	989.8	14.2
1915-17	990.4	994.2	990.8	993.8	998.3	993.4	986.9	999.7	988.0	983.0	993.2	993.4	992.1	16.7
Seasons	992.6			994.3			993.3			988.1				

TABLE XIX. DIURNAL PERIODIC PRESSURE VARIATION (mb), CAPE EVANS

	3 a.m.	7 a.m.	11 a.m.	3 p.m.	7 p.m.	11 p.m.
Δp 1916	-.09	-.11	.03	-.07	.11	.12
Δp 1915-16	-.11	-.07	.03	-.01	.10	.06
Sunshine (Oct-Feb)	-.06	-.07	.06	-.08	.05	.15
Darkness (Apr-Aug)	-.14	-.05	-.02	.03	.10	.06

TABLE XX. INTERDIURNAL PRESSURE VARIATION 1915-17 (mb), CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
rising pressure	2.1	5.5	5.0	4.6	4.9	5.8	7.3	6.3	5.8	4.6	4.1	2.9	4.9
falling pressure	-3.6	-3.2	-4.4	-4.6	-4.8	-5.5	-7.5	-4.3	-5.1	-5.1	-4.0	-3.7	-4.6
mean	2.7	4.1	4.7	4.6	4.9	5.6	7.4	5.1	5.4	4.8	4.0	3.3	4.7

TABLE XXI. INTERDIURNAL PRESSURE VARIATION AT McMURDO SOUND

January				April				July				October				Year			
n	rise	fall	all	n	rise	fall	all	n	rise	fall	all	n	rise	fall	all	n	rise	fall	all
132	3.0	-3.6	3.3	180	4.9	-5.1	5.0	186	7.7	-6.9	7.3	186	5.0	-5.3	5.1	684	5.1	-5.2	5.2

TABLE XXII. EXTREME MONTHLY PRESSURE 1915-16 (900 mb+), CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Max.	99.9	107.6	102.7	114.2	119.6	111.5	115.2	122.2*	109.7	107.4	104.6	113.1	1022.2*
Min.	73.6	76.3	73.8	75.0	80.5	68.5	52.1*	72.2	54.9	64.8	73.6	83.1	952.1*
Range	26.3	31.3	28.9	39.2	39.1	43.0	63.1	50.0	54.8	42.6	31.0	30.0	70.1

(values with asterisk are extremes for 7 years)

TABLE XXIII. MEAN MONTHLY WIND SPEED, m/sec, 1915-1917, CAPE EVANS

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Year
n	222	274	224	360	372	360	372	372	360	296	329	370	3811
m/sec	6.3	11.9	10.0	10.4	8.4	8.9	10.9	7.7	10.5	7.6	10.4	6.6	9.1

TABLE XXIV. PERCENTAGE FREQUENCIES OF DIFFERENT WIND SPEEDS, 1915-1917, CAPE EVANS

Miles/hour		0-3	4-8	9-13	14-18	19-23	24-28	29-34	35-40	41-48	49-56	57-65	66-75	75
m/sec		0-1	2-4	4-6	6-8	8-10	11-12	13-15	16-18	19-21	22-25	25-29	29-33	33
Beaufort	n	0	1	2	3	4	5	6	7	8	9	10	11	12
Jan	231	15	36	12	6	9	3	5	3	2				
Feb	174	4	8	7	9	12	14	20	8	13	4	1		
Mar	216	4	15	12	12	11	4	10	9	6	6	1		
Apr	357	8	22	13	9	5	5	5	13	12	6	2	.3	
May	381	22	17	12	8	6	5	6	11	7	4	2	.3	.3
Jun	360	19	22	10	6	2	6	8	11	8	6	2	.3	
Jul	370	26	19	9	5	3	6	5	10	14	11	2		
Aug	372	29	20	9	5	6	7	6	8	4	5	1	.3	
Sep	357	18	16	10	5	5	7	6	10	10	7	4	1	.6
Oct	294	22	15	11	13	7	5	10	8	1	.7	.3		
Nov	327	8	12	10	7	11	11	16	14	7	4	.3		
Dec	361	10	26	19	13	10	7	7	6	2	.6			
Spring	978	16.0	14.5	10.0	8.5	7.5	8.0	9.5	11.0	8.0	4.0	1.5	.5	.2
Summer	766	10.0	25.0	14.0	10.0	10.0	9.5	8.5	6.0	5.0	1.5	.1		
Autumn	954	12.5	18.5	12.5	9.5	6.5	7.0	6.5	11.5	8.5	5.0	2.0	.2	.1
Winter	1102	21.0	20.5	9.0	5.5	4.0	6.0	6.5	9.5	9.0	7.0	1.5	.2	
Year	3800	15.4	19.3	11.2	8.1	6.8	7.4	7.6	9.7	7.9	4.7	1.4	.3	.1
*		3.85	3.86	2.24	1.62	1.36	1.48	1.27	1.62	0.99	0.59	.15	.03	.01

*the wind frequencies in equal steps of one mile per hour.

TABLE XXV. FREQUENCY OF ALL DAYS WITH GALE, AND DAYS WITH STRONG GALE, 1915-1917, CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
days with gale	8	16	12	16	14	15	18	11	14	11	15	7	157
% of time	9	25	14	33	23	28	38	18	29	20	24	9	22
days with strong gale	3	5	3	7	6	7	10	6	9	4	5	1	66
% of time	2	4	3	8	7	7	10	8	12	3	3	1	6

TABLE XXVI. PERCENTAGE DISTRIBUTION OF WIND DIRECTIONS, 1915-1917, CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Gales
n	219	174	222	366	365	359	370	360	358	297	330	364	3784	529
N	4	1	9	11	10	6	6	10	3	9	2	10	7	0.4
NE	5	1	6	6	12	8	7	3	1	3	1	4	5	0.3
E	8	17	24	15	9	13	12	5	10	7	11	7	11	1
SE	73	76	51	44	55	55	59	57	67	60	74	60	61	97
S	1	3	5	18	6	6	1	3	4	3	3	2	4	1
SW	2	1	2	0	0	0	1	0	1	0	1	1	1	0
W	0	0	0	1	1	1	2	0	0	0	0	2	1	0
NW	2	0	2	2	2	3	2	2	2	10	5	10	3	0
Calm	5	1	1	3	5	8	10	20	12	8	3	4	7	0

TABLE XXVII. DIURNAL VARIATION OF WIND IN m/sec, 1915-1917, CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Oct-Feb	Mar & Sep	Apr-Aug	Year
days	37	29	31	60	62	60	62	62	60	31	51	62	210	91	366	667
3 a.m.	5.9	12.5	10.0	11.2	7.8	8.4	10.7	7.0	10.0	8.5	10.1	6.0	8.6	10.0	9.0	9.0
7 a.m.	5.9	11.5	8.6	10.3	7.0	9.9	10.5	7.9	10.0	8.3	9.9	6.2	8.4	9.3	9.1	8.8
11 a.m.	6.1	11.7	10.0	10.1	6.5	9.3	10.5	7.4	10.6	8.8	11.2	7.3	9.0	10.3	8.8	9.1
3 p.m.	6.3	12.2	10.6	10.8	8.2	9.3	11.4	7.5	11.5	10.2	11.7	7.6	9.6	11.1	9.5	9.8
7 p.m.	6.7	12.0	9.7	9.7	7.8	8.3	10.9	7.1	10.3	9.4	10.5	6.7	9.1	10.0	8.8	9.1
11 p.m.	6.4	11.3	8.7	10.3	8.0	8.9	10.5	7.3	9.9	8.8	10.3	5.9	8.6	9.3	9.0	8.9
Mean	6.2	11.8	9.6	10.4	7.5	9.0	10.8	7.4	10.4	9.0	10.7	6.2	8.8	10.0	9.0	9.1
Range	0.8	1.2	2.0	1.4	1.7	1.6	0.9	0.9	1.6	1.9	1.8	1.7	1.2	1.8	0.7	1.1

TABLE XXVIII. PERCENTAGE OF VERY WEAK WINDS, 0-1 m/sec, AT DIFFERENT HOURS, 1915-1917, CAPE EVANS

	April-Sept.	Oct.-March	Year	May-July
n	301	111	422	222
3 a.m.	15	25	17	16
7 a.m.	17	23	19	18
11 a.m.	19	16	18	17
3 p.m.	13	12	12	14
7 p.m.	19	13	18	20
11 p.m.	17	13	16	15

TABLE XXIX. PERCENTAGE DISTRIBUTION OF DIRECTION OF WIND AT SUMMIT OF EREBUS, 1915 AND 1916

	n	N	NE	E	SE	S	SW	W	NW
Observations	316	8	3	2	14	18	6	8	40
Days	245	10	3	2	17	23	3	10	32

TABLE XXX. MONTHLY MEANS OF RELATIVE HUMIDITY, 1915-1917, CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
3 a.m.	83	77	72	75	79	80	82	78	82	85	78	82	80
7 a.m.	83	78	74	73	80	80	82	76	81	83	75	77	78
11 a.m.	81	77	72	68	79	83	83	75	83	84	76	79	78
3 p.m.	82	76	69	75	73	82	82	79	81	84	74	76	78
7 p.m.	85	73	71	73	78	80	81	78	80	85	77	78	78
11 p.m.	87	78	71	78	78	80	79	79	81	84	78	84	80
Mean	84	77	71	74	78	81	81	77	81	84	76	79	79
Ice equal at %	94	96	88	86	81	83	80	80	80	84	92	94	86

TABLE XXXI. DIURNAL VARIATION OF MEAN WATER VAPOR PRESSURE AND RELATIVE HUMIDITY DURING DECEMBER AND JANUARY, 1915-17, AT CAPE EVANS

	3 a.m.	7 a.m.	11 a.m.	3 p.m.	7 p.m.	11 p.m.
t_m	- 6.9	- 5.8	- 4.5	- 4.5	- 5.5	- 6.9
mb H_2O	3.2	3.3	3.5	3.6	3.4	3.3
R. H.	82.5	80.0	80.0	79.0	81.5	85.5

TABLE XXXII. DIURNAL VARIATIONS OF RELATIVE HUMIDITY AND TEMPERATURE, MAY TO JULY, 1915 AND 1916, CAPE EVANS

	3 a.m.	7 a.m.	11 a.m.	3 p.m.	7 p.m.	11 p.m.
Δ R. H. %	.3	.6	1.6	-1.0	- .4	-1.0
Δ t	.03	-.19	.00	.01	.00	.16

TABLE XXXIII. EVAPORATION OF LAKE ICE AT CAPE EVANS, 1915-1916

Period	days	Mean temp.	Mean max.	Extreme max.	Evapn., mm	mm/day
24VI-25IX '15	63	-21.0	-18.3	-4.4	15.3	.08
19IV-12X '16	176	-20.4	-16.5	-5.4	18.3	.10
13X-16XI '16	35	-13.6	-10.4	-5.4	18.5	.53

TABLE XXXIV. MEAN MONTHLY CLOUDINESS IN OCTAS AND NUMBER OF CLEAR AND OVERCAST DAYS, 1915-1917, CAPE EVANS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
cloudiness	5.2	6.1	5.2	5.0	3.9	4.0	5.0	3.2	4.8	5.9	5.1	5.0	4.9
clear days	6	2	1	2	7	5	4	12	6	2	3	3	53
overcast days	16	16	12	11	6	6	14	4	11	16	12	9	133

TABLE XXXV. PERCENTAGE FREQUENCIES OF CLOUDINESS (1/10), 1915-1917, CAPE EVANS

Cloudiness	n	0	1	2	3	4	5	6	7	8	9	10
Jan	227	14	6	7	4	3	3	1	4	5	7	41
Feb	176	2	6	6	3	4	3	4	3	8	16	45
Mar	185	5	11	6	6	3	2	3	5	8	17	33
Apr	359	5	15	7	4	6	3	3	3	5	14	35
May	352	16	20	7	6	5	3	3	5	4	8	23
Jun	344	20	11	8	8	5	2	2	4	3	9	29
Jul	368	8	12	6	6	5	2	1	5	4	7	43
Aug	370	20	21	12	6	5	2	4	3	4	5	20
Sep	343	13	12	6	3	6	1	3	4	5	10	37
Oct	283	8	7	3	2	3	2	3	4	5	11	53
Nov	308	10	9	5	5	5	3	4	5	7	11	37
Dec	316	5	8	9	9	6	7	4	7	7	13	26
Spring	934	10	9	5	3	5	2	3	4	6	11	42
Summer	719	7	7	7	6	5	4	3	5	7	12	37
Autumn	896	9	15	7	5	5	3	3	4	6	13	30
Winter	1082	15	15	9	7	5	2	2	4	4	7	30
Year	3631	10	11	7	5	5	3	3	4	6	11	35
Oct-Feb	1310	8	7	6	5	4	4	3	5	6	12	40

TABLE XXXVI. DIURNAL VARIATION OF CLOUDINESS (/10) IN SUMMER, AT CAPE EVANS

	3 a.m.	7 a.m.	11 a.m.	3 p.m.	7 p.m.	11 p.m.
1915-16	-.05	-.15	+.05	+.15	+.15	-.15
1911-12	-.2	-.1	+.3	+.2	+.1	-.1